ON THE EFFECT OF POWER CONSUMPTION MODEL ON WSN ROUTING TECHNIQUES

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DEDICATION

I dedicated this thesis to my family, especially…:

To my beloved Parents for instilling the importance of hard work and higher education…..

To my brothers and sister for their kind help ……

To Nesreen and Fatima…….

AKNOWLEDGEMENT

Firstly, I am extremely grateful to Almighty, Allah who bestowed me the understanding and perseverance to make this accomplishment possible. And I would like to express my deepest gratitude to my supervisor to Prof. Saleh Al-Shareah for his valuable advice and moral support during research period.

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We would like to acknowledge the work of Al-Sharaeh et al and the previous work of Reema Hosni Master Thesis, in which we use the same style and format in writing and showing the results, in order to make a fair comparison between our work and their work. And I would like to acknowledge Prof. Saleh Al-Sharaeh for providing the idea and the basic code of this research.

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LIST OF ABBREVIATIONS OR SYMBOLS

Meaning	Symbol or Abbreviation
Wireless Sensor Network	WSN
Online Maximum Lifetime Heuristic	OML
Capacity Maximization	CMAX
Efficient Routing Power Management Technique	ERPMT
Efficient Routing Power Management Technique Based on OML	ERPMT_O
Efficient Routing Power Management Technique Based on CMAX	ERPMT_C
Efficient Routing Power Management Technique Based on OML using Heinzelman equations and realistic variables	ERPMT_OH
Efficient Routing Power Management Technique Based on CMAX using Heinzelman equations and realistic variables	ERPMT_CH
Directed Acyclic Graph	DAG
The ratio of total node energy dedicated for data originated from the node itself	α
The ratio of total node energy dedicated for data relays from other nodes	β

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ABSTRACT

A wireless sensor network (WSN) consists of a large number of sensor nodes. A sensor node includes a processor, wireless radio and various sensors. Sensor nodes are powered by batteries with a limited capacity. Since the radio is the main cause of power consumption in a sensor node, transmission/reception of data should be limited as much as possible.

It is necessary to use energy conserving routing algorithms to find paths which consume minimum energy. Recent researches on maximizing the lifetime of WSN, such as the Online Maximum Lifetime (OML), and Capacity Maximization (CMAX) heuristic were designed to maximize the lifetime of sensors in WSN.

A new efficient routing power management heuristic was introduced to gain higher lifetime by managing the power at the node level by dividing the node energy into two ratios; one for the sensor node originated data (α) and the other is for data relays from other sensors (β). This heuristic, which called ERPMT (Efficient Routing Power Management Technique), has been applied to OML and CMAX to get the modified versions of them, which are ERPMT_O and ERPMT_C respectively in order to study the

effect of that on the network lifetime, the study based on statistical analysis using random variables.

In this thesis, we introduce a realistic power consumption model based on Heinzelman equations, using realistic variables. such as, the message size, the distance between nodes and the initial power for each nodes, the model is used to compute the consumption of transmission/ receiving power in each node a long the shortest path that found by OML, CMAX, ERPMT_O and ERPMT_C, after applying the realistic model on the heuristics, new heuristics are introduced, CMAX_H, OML_H, ERPMT_CH, and ERPMT_OH. We also study the effects of terrain heterogeneity by implementing the new heuristics based on Uniform and Poisson distributions.

After execution extensive simulation runs using our consumption model, results revealed the superiority of using the power management technique that is proposed in this thesis, over the heuristics OML_H and CMAX_H. ERPMT_OH gained best lifetime is 74.20% when $\alpha = 10\%$ over the other three heuristics when it is implemented in Uniform distribution, for the other distributions the lifetime averages that were gained by other heuristics for all cases of different power divisions, there is not static strategy for decreasing or increasing in lifetime average for these heuristics.

Furthermore, the results of implementing a wireless sensor system MICAz using the realistic consumption model achieved higher average lifetime in Uniform distribution than the Poisson distribution.

1. Introduction

1.1. Overview, Challenges, and Power Aware Routing in WSN

A wireless sensor network consists of sensor nodes deployed over a geographical area for monitoring physical phenomena like temperature, humidity, vibrations, seismic events, and so on. Typically, a sensor node is a tiny device that includes three basic components: a sensing subsystem for data acquisition from the physical surrounding environment, a processing subsystem for local data processing and storage, and a wireless communication subsystem for data transmission, (Giuseppe Anastasi, 2009).

A power source supplies the energy needed by the device to perform the programmed task. This power source often consists of a battery with a limited energy budget. In addition, it could be impossible or inconvenient to recharge the battery, because nodes may be deployed in a hostile or unpractical environment. The data being sensed by the nodes in the network must be transmitted to a control center or base station, where the end-user can access the data. On the other hand, the sensor network should have a lifetime long enough to fulfill the application requirements; energy conservation is a key issue in the design of systems based on wireless sensor networks, (Koushik, 2003).

The network lifetime in this work is defined as the number of successful messages routed until the first fail request. Since some battery energy is depleted for each message transmission, it is necessary to use energy aware and energy conserving routing algorithms, (Koushik, 2003).

There have been several network routing protocols proposed for wireless that are categorized according to the way they transmit the data to the base station or sink node: direct communication with the sink node, multi-hop and clustering approach. Using a direct communication protocol, each sensor sends its data directly to the sink. If the sink node is far away from the nodes, direct communication will require a large amount of transmit power from each node. This will quickly drain the battery of the nodes and reduce the system lifetime and cause blind areas and network partitions, multi-hop approach nodes route data destined ultimately for the sink node through intermediate nodes. Thus nodes act as routers for other nodes' data in addition to sensing the environment, in clustering approach, the nodes organize themselves into local clusters, with one node acting as the local sink node or cluster-head, If the cluster heads were chosen a priori and fixed throughout the system lifetime, as in conventional clustering algorithms, the sensors chosen to be cluster-heads would die quickly, in some clustering routing protocols such as LEACH includes randomized rotation of the high-energy cluster-head position such that it rotates among the various sensors in order to not drain the battery of a single sensor, (Koushik, 2003).

We will take into account two of these routing heuristics, which try to delay the early depletion of sensors energy: The first heuristic we have used is OML (Online Maximum Lifetime), which employs two shortest path computations to route each message. To maximize lifetime, it is recommended to delay as much as possible the depletion of a sensor's energy to a level below that needed to transmit to its closest neighbor. The second heuristic is CMAX (Capacity Maximization) heuristic which makes admission control. That is, it rejects some routes that are possible. OML was

chosen because it achieves the best lifetime in the literature. And because it was built as a modification for CMAX, we also consider CMAX to study the effects of applying the proposed technique on it.

We will also take into account a new approach applied along with OML and CMAX, the new heuristics are called ERPMT_O and ERPMT_C respectively, in ERPMT_O and ERPMT_C they performing a battery power management at the node level, such that the total power of the sensor battery is divided into two parts; the first is dedicated for sending data generated by the sensor itself, while the other is for data relays from other sensors, the division is done in different ways to test each combination effect. The four heuristics (OML, CMAX, ERPMT_O and ERPMT_C) were studies and analyzed based on statistical analysis using random variables.

We introduced a new realistic power consumption model based on Heinzelman equations, the new model was used along with the four heuristics (OML, CMAX, ERPMT_O and ERPMT_C) to compute the transmission energy and receiving energy in each node, we will study and compare the four techniques in a realistic way, by using realistic variables.

We embed a realistic power consumption model using a realistic messages size, also we assume a simple model where the radio dissipates 50 nJ/bit to run the transmitter or receiver circuitry and 100 pJ/bit/m2 for the transmit amplifier (Heinzelman, 2000), the sensor network is represented by an adjacency matrix that was generated depending on the Euclidian dimensions of the network nodes, such that they were compared to a threshold in order to determine if there is connectivity (edge) or not between every two nodes.

The ERPMT (ERPMT_OH and ERPMT_CH) are compared against two well known routing heuristics: OML_H and CMAX_H. We studied the dimension effects (1D and 3D) Also, we took into consideration the heterogeneity of the deployment environment. For example, Uniform and Poisson distributions imitate flat and uneven terrains respectively, (Al-Sharaeh, et al., 2008).

What distinguishes our work from previous researches is using realistic variables in power consumption computation, and we compute the receiving power also to each node which was not represented in the previous four heuristics, in this work we also studied and analyzed real WSN system which is called (MICAz).

1.2. Research Objectives

Our study has number of objectives which are done and discussed through the thesis, they are:

(a) Implementing and evaluating existing heuristics using Uniform distribution.

(b) Implementing and evaluating the existing heuristics using Poisson distribution.

(c) Implementing and evaluating the realistic power consumption model using Uniform and Poisson distribution.

(d) Implementing the realistic power consumption model using 3D, and study the effect of changing from 1D to 3D.

(e) Comparing the results of different combinations of implementations and study their effect on average lifetime.

(f) Comparing the result of our power consumption model based on Heinzelman equations with real case study (MICAz)

This thesis is organized as follows:

In this Chapter, we presented an overview on wireless sensor networks and, a problem overview, main challenges, power aware routing methods, and finally the objectives of the proposed system were discussed. In the second Chapter, other existing studies in the literature for maximizing network lifetime were introduced. In the third Chapter, a description of details of sensor network deployment and system implementation is provided. Also, the realistic power consumption model is presented. Experiments and the evaluation of the results for the proposed model using different

types of distributions and different network size are given in the fourth Chapter. Finally, the thesis is concluded and the future work is mentioned in the fifth Chapter.

2. LITRATURE REVIEW

Wireless sensor networks have their own unique characteristics which create new challenges for the design of routing protocols for these networks. First, sensors are very limited in transmission power, computational capacities, storage capacity and most of all, in energy.

Singh et al. (1998) proposed the Min–Max battery cost routing (MMBCR) which tries firstly to find the node that having the minimum battery capacity in all possible routes, then MMBCR tries to select the route that has the maximum lifetime, this operation depend on the residual battery power capacity metric. MMBCR does not take into account the transmission power of nodes.

Rodoplu and Meng (1999) introduced MECN, in the MECN each sensor has a relay region which has the less number of nodes and requires the less power to make transmission between any two pair of nodes that belong to the relay region, each sensor in the network is responsible to make a localized search that determine it's relay region, the key property of the relay region constructed by MECN is the minimum energy property, it guarantees that between any connected pair of nodes there is a minimum energy path which is found without take into consideration all the nodes into the network.

Heinzeleman (2000) proposed LEACH, in the low energy adaptive clustering hierarchy protocol the nodes organized themselves into local clusters, each local cluster has a head cluster which are chosen randomly to be local base station, if the cluster heads were chosen to be fixed along the network lifetime they will die quickly, so the LEACH performs a randomized rotation in cluster heads selection operation which is limited to

the high energy cluster heads to prevents battery depletion in cluster head nodes. Nodes decide to which cluster it belongs according to the minimum communication energy, within each clusters nodes access the channel using TDMA (MAC). When all nodes decide to which cluster it belong, the other non clustered nodes turned off their transceiver all the time except in transmission time. Cluster heads aggregate the data from the nodes and then it sends the data to the base station.

Li and Halpern (2001) introduced (SMECN), the Small minimum energy communication network is an extension to MESN, it consider the obstacles between any pair of nodes unlike MECN which assumes each node can transmit to other nodes. He relay region or the sub-network that is constructed by SMECN is smaller number of edges than the sub-network that is constructed by MECN. More overhead is made by SMECN because of finding sub-network with smaller number of edges. Results show the superiority of SMECN over MECN, SMECN consumes less energy.

Manjeshwer and Agarwal (2001) proposed TEEN which is hierarchical clustering protocol, it is similar to LEACH except that sensor nodes do not transferred data periodically, but it sensed data constantly. Each cluster head in TEEN broadcasts two kind of threshold (hard threshold and soft threshold), nodes belong to a cluster can transmit data to the cluster using time slot only in two cases: 1) if the sensed data is bigger than the hard threshold, 2) if the sensed data differs from last transmitted value by more than the soft threshold, after the transmission the soft threshold is rest. Since TEEN do not transfers data periodically; it is not suitable for applications that need periodic reports.

Toh (2001) proposed the Conditional Max-Min battery Capacity Routing (CMMBCR) which takes into account the residual energy in the nodes and the total transmission energy consumption of routes, choosing the minimum total transmission energy will maximize the lifetime of the network by distributing power consumption evenly on the nodes. CMMBCR is considered a hybrid approach.

Li, et al. (2001) introduced the Hierarchical Power-Aware Routing in Sensor Networks, sensors in this protocol is grouped based on geographic metric and forms a zone. Each zone can determine the way to route a message within the other zones using max-min path that has the maximum over all the minimum of the residual power.

Manjeshwer and Agarwal (2002) proposed APTEEN which is the Adaptive Threshold sensitive Energy Efficient sensor Network protocol; it is an enhancement to TEEN. In APTEEN, each cluster head will sends the hard and soft threshold , APTEEN aiming to capture time critical events and periodic data collection, cluster heads sends transmission schedule beside sending the two threshold, TDMA schedule is used where each node in the network get it’s time slot to start transmission to the cluster head. As in TEEN forming clusters in multiple levels causes overheads and complexity.

Lindsey and Raghavendra (2002) proposed PEGASIS which collects data by forming a chain, each node can receives and transmits data to the close neighbor node, by doing so, the number of nodes that communicating directly with the base station can be reduced by let each node to take a turn to be the leader for transmission to the base station per round, this technique can balance energy consumption in the network, PEGASIS outdoes LEACH’S performance by avoiding the overhead of forming clusters.

Misra and Banerjee (2002), proposed the MRPC (Maximum Residual Packet Capacity) lifetime-maximization which defined the capacity of node by thr residual battery energy and the expected transmission energy that could be spent in reliable forwarding packet over selected path, MRPC considers a route to be the maximum residual lifetime which can balance the load over the network and increases network lifetime.

Kar (2003), introduced the Capacity Maximization protocol (CMAX), CMAX focuses on maximizing the number of messages that routed in period of time, the protocol try to find a single path for the each message, the path is chosen according to the weight of the link, where each link is given a weight by weight function, CMAX can rejects some route to increase the lifetime.

Park and Sahni (2006), introduced OML (Online Maximum Lifetime) which is a modification over CMAX , the heuristic performs tow shortest path computations for each message waiting to route, it's important to delay the sensor's energy depletion to a level below that needed to transmit to nearest node.

Al-Sharaeh, et al. (2008), introduced a heuristic which takes into consideration the multi-dimensional concept and position distribution to evaluate the routing heuristics. As moving to higher dimension the representation of the network become more realistic. they also used the Poisson distribution which represents realistic network deployment better than Uniform distribution. A major effect on the performance of different routing heuristics was gained.

Al-Sharaeh, et al. (2009), introduced a study of the deployment strategy effect on maximizing the lifetime of the wireless sensor networks; it shows that changing the

statistical techniques of distribution such as Poisson distribution that meet real environment requirements affect the performance of maximizing lifetime routing heuristics in many aspects, such as average lifetime and network capacity.

Chunming, et al. (2009) proposed a new energy saving routing algorithm to enhance the performance and the lifetime of the ad hoc networks, ES-DSR modified DSR protocol where the routes energy and count of hops are considered comprehensively in the routing cost function, these two parameters are adjusted in the algorithm according to the nodes energy, ES-DSR improve the lifetime and performance of the network.

Liu, et al. (2009) proposed EAP (energy-aware routing protocol) which minimize the energy consumption for in-network communication and balance the energy load through the nodes. In EAP the cluster-head election process is based on a clustering parameter which can handle the heterogeneity of energy capacities, the area coverage problem is coped by intra-cluster coverage approach where the number of working nodes within a cluster is reduced and a routing tree among cluster heads is built for energy saving communications.

Balaswamy, et al. (2011) introduced a mechanism of periodic route discovery to get more updated information about routes in MMBCR protocol to avoid using the same selected route until the request fail; due to the exhaustion of node battery energy. The periodic route discovery mechanism increased the network lifetime.

We can understand from the previous researches on conserving the network power by working on routing protocols the importance of increasing the average life time of the network, in our work we study and analyzed four heuristics of power conserving protocols using realistic consumption model.

3. Theory and Implementation

3.1. Sensor network model

A wireless sensor network can be modeled as a graph **G= (V, E)**, where **V** represent the set of nodes in the network and **E** the set of edges between nodes who have a link between them, The energy consumed for transmitting a unit message along link **(u,v)** $\in$ **V**

is represented by e_{uv}, (kar, 2003). for each **(u, v)** $\in$ **E**, in case of single hop transmission from sensor **u** to sensor **v**, the current energy in sensor u, $c_e(u)$ is represented by Equation 3.1 (Park and Sahni, 2006).

$$c_e(u) = c_e(u) - w(u,v) \qquad (3.1)$$

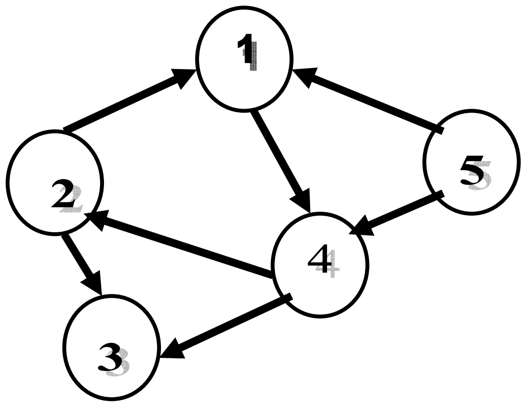
Where $c_e(u)$ is the current energy in sensor u, such as $c_{e(u)} \leq w(u,v) \leq 0$, and w(u,v) represent the power required to make a single hop, it is calculated by weight function, in last studies, weight function based on hypothetical variables and the receiver of a message consumes no energy during message reception.

In our study, we represent the realistic required power to make a single hop transmission by $E_{TX}(k,d)$, the transmission power is calculated based on realistic variables, where k is the message size and d is the distance between two nodes have a direct link between them, we also assume that the receiver of a message consumes energy during message reception. The receiving power is represented by $E_{RX}(k,d)$, The receiving power is calculated based on realistic variables (Heinzelman, 2000).

Reema Hosny (2009) introduced new power management technique, where the energy at node level is divided into two ratios, one for data originated from the node (α), the other is for relays from other sensors (β); if the data is originated from the node itself, it will use the energy from the first ratio otherwise it will use energy from the other ratio.

An adjacency matrix can be used to represent directed graphs of WSN (Park and Sahni, 2006; Al-Sharaeh, et al., 2008; Al-Sharaeh, et al., 2009). The adjacency matrix of a finite directed graph **G** on n vertices (where n = |V|), is the $n \times n$ matrix such that, the non-diagonal entry a (i, j) = 1, represents the existence of an edge from sensor i to sensor j. While the diagonal entry a(i, i) is assigned by zeros here because we assume that there is no internal loops in the WSN.

Every graph has its unique adjacency matrix for each for example, Fig. 3.1.(a) shows a simple representation for sensor network S. A directed graph is used, where the represented nodes are sensors, and the edges represent the existence of edges between the sensor nodes. Fig.3.1. (b) Shows the adjacency matrix of the sensor network S modeled in Fig. 3.1.(a). It is obvious that Fig. 3.1.(b) Depicts a network that has been implemented using one dimension to represent sensors. Such representation for sensors has been used by (Al-Sharaeh, et al., 2009) in previous studies. In order to get more realistic results, we also represent sensors using 3D (3 dimensional) in one of our experiments; each sensor is represented using three dimensions: x, y, and z (Al-Sharaeh, et al., 2009).



	1	2	3	4	5
1	0	0	0	1	0
2	1	0	1	0	0
3	0	0	0	0	0
4	0	1	1	0	0
5	1	0	0	1	0

(a): Simple graph network representation (b): Corresponding adjacency matrix representation

Figure 3.1: Representation of wireless sensor network

In most of the studies to represent a sensor location as well as connectivity a random number from Uniform distribution was used (Park and Sahni, 2006; Kar 2003).

In order to assume realistic variables in our work the distance ***d*** between any two sensors have a link between them, is represented by a random number limited to real distance interval, d is used in the transmission power computation.

It is better to use the Uniform distribution for flat terrain environment, because the sensors can be distributed evenly as shown in Fig. 3.2, but the real environment usually characterized by terrains, such as in case of sensors deployed in high mountains or deep oceans. In this case, the Uniform distribution does not give a good realistic that match the terrain changes. For that, it is better to use Poisson distribution as it is best fits the asymmetric environment (Al-Sharaeh, et al., 2008; Al-Sharaeh, et al., 2009). Fig.3.3 shows sensor nodes distribution based on Poisson distribution, it is clear that the sensors

location concentrated around the mean. This kind of deployment imitates a deployment of sensors via airplane in a terrain that is close to valleys.

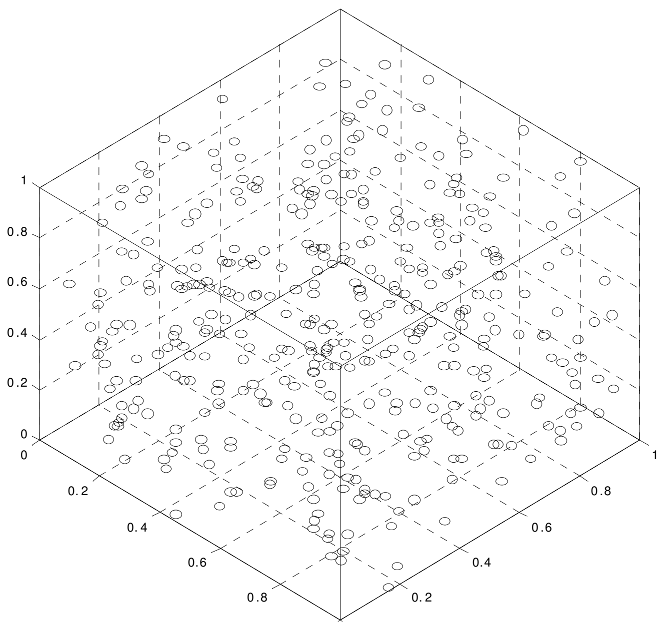


Figure 3.2: 3D Sensor nodes distribution based Uniform distribution (Reema Hosny, Efficient Routing Technique That Maximize the Lifetime and Coverage of Wireless Sensor Networks, master thesis, 2009)

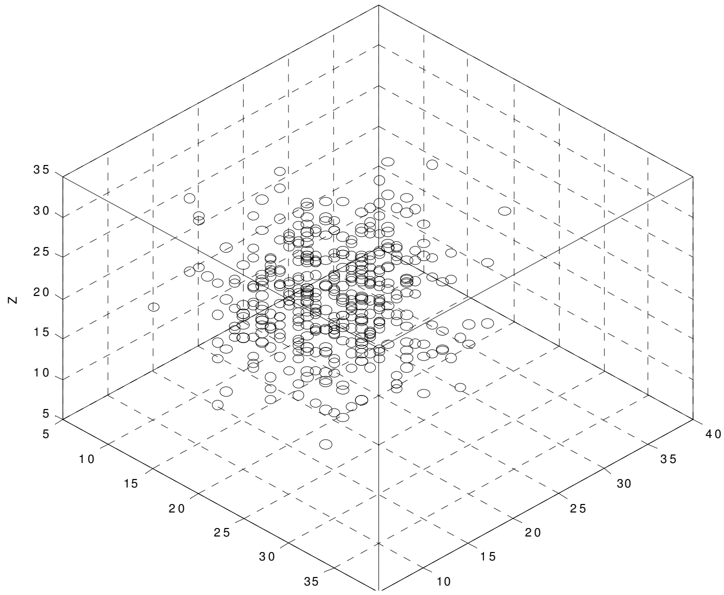


Figure 3.3: 3D Sensor nodes distribution based Poisson distribution (Reema Hosny, Efficient Routing Technique That Maximize the Lifetime and Coverage of Wireless Sensor Networks, master thesis, 2009)

To determine connectivity between the nodes, we used a threshold which was equal to the mean of the dimensions of network nodes. All nodes were recursively checked by comparing their X-, Y- and Z-dimension in case of 3D deployment with the mean of the Euclidian dimensions for these 3 dimensions (X, Y, and Z) for all network nodes. For the case of 1D, we only work with just the X dimension. Each node with a dimension value greater than or equal to the mean of the same dimension will be considered connected, otherwise it will be disconnected (Park and Sahni, 2006). For example, if the X dimension of node A was equal to 8, and there are other three nodes in the network with their X dimensions equal to 14, 10, and 18. To determine if node A is connected we compare its X dimension with the threshold which is the mean of all network node

dimensions and this is equal to 50(14 + 10 + 18+ 8). Node A is considered not connected because 8 is not larger than the average of (14, 10, 18 and 8).

3.2. Details of energy-aware routing heuristics used

We have used OML and CMAX heuristics to apply our realistic consumption model on, and another two heuristics represent a new power management technique were applied to CMAX and OML in previous work, the result was generating two new heuristics ERPMT_C and ERPMT_O, in our study we applied the new consumption power model on the last four heuristics, different heuristics were proposed to extend the lifetime of the network, OML obtained the best lifetime in the literature.

The first heuristic used CMAX (capacity maximization) heuristic which makes admission control. That is, it rejects some routes that are possible (Kar, 2003). Using CMAX (capacity maximization) heuristic, each link in the network (u, v), is represented by a corresponding weight w (u, v), CMAX performs two steps: at first step the algorithm eliminate from the graph any edge (u, v) for which:

$$c_{e1}(u) < w(u, v)$$

Then the algorithm changes the weight to each remaining edge (u, v) in the graph to:

$$w(u,v) = w(u,v) * \lambda_c^{\,a(u)} - 1 \qquad (3.2)$$

Where λ_c is a heuristic parameter, $a(u)$ is the percentage of the initial energy that has Already been spent at the sensor node and calculated as:

$$\mathbf{a(u)} = \begin{cases} \mathbf{1 - c_{e1}(u)/i_e(u)} \\ \mathbf{1 - c_{e2}(u)/i_e(u)} \end{cases} \qquad (3.3)$$

In the second step of CMAX, a shortest source-to-destination path Pi in the modified Graph is determined, after obtaining the path, two options are available: If no path is found in second step, the route is not possible. If path is found, the algorithm Uses Pi for route if its length is less than specific threshold (σ).

Reema Hosny (2009) add an enhancement on CMAX by dividing the power at node level (current energy) to two ratios: the first is for the sensor originated data (α), the other is for relays from other sensors (β).

The Second heuristic is OML (Online Maximum Lifetime), which delay as much as possible the depletion of a sensor's energy to a level below that needed to transmit to its closest neighbor, to accomplish this objective using a two-step algorithm to find a path for each routing request $r_i = (s_i, t_i)$ In the first step, is starting by remove from G all edges (u,v) such that $ce(u) < w(u,v)$ as these edges require more energy than available for a transmit. The result is the graph $G' = (V, E')$. Next operation is determining the minimum energy path, P'_i from s_i to t_i in the pruned graph G'. This may be done using Dijkstra's shortest path algorithm, (Singh, 1998; G. Li, 2001). In case there is no s_i to t_i path in the pruned graph G', the routing request r_i fails. Else, the algorithm assumes such a P'_i exists. Using P'_i, a computation of the residual energy, $re(u) = ce(u) - w(u,v)$ for (u,v) an edge on P'_i, then the algorithm computes the $\min RE$ where $\min RE = \min\{re(u) | u \in P'_i \wp \wp u \neq t_i\}$, a G'' graph is obtained by removing all edges from graph G' where $(u,v) \in E'$ with $ce(u) - w(u,v) < \min RE$ In the second step, we find the path to be used to route the request r_i by assign weights to each

$(u,v) \in E''$, the weight assignment is done so as to balance the desire to minimize total energy consumption as well as the desire to prevent the depletion of a sensor's energy, where:

The new weight assigned as:

$$w''(u,v) = (w(u,v) + \rho(u,v))(\lambda^{a(u)} - 1) \qquad (3.4)$$

λ is non-negative constant and an algorithmic parameter.

The $\rho(u,v)$ is defined as:

$$\rho(u,v) = \begin{cases} 0 & \text{if } ce(u) - w(u,v) \succ eMin(u) \\ c & \text{otherwise} \end{cases} \qquad (3.5)$$

c is a non-negative constant and is an algorithmic parameter.

And for each $u \in V$, define as:

$$a(u) = \frac{minRE}{ce(u)} \qquad (3.6)$$

Then, the shortest path P''_i can be found from G''.

Reema Hosny (2009) added an enhancement on OML by dividing the power at node level (current energy) to two ratios: the first is for the sensor originated data (α), the other is for relays from other sensors (β).

we apply a new technique to assign a realistic weight to the edges, where the required transmission and receiving power are computed according to the first order

model, where Different assumptions about the radio characteristics, including energy dissipation in the transmit and receive modes (Heinzelman ,2000), the first order model assumes the radio dissipates E_{elec} = 50 nJ/bit to run the transmitter or receiver circuitry and $€_{amp}$ = 100 pJ/bit/m2, Table (3.1).

Operation	Energy Dissipated
Transmitter Electronics (E_{Tx_elec}) **Receiver Electronics (E_{Rx_elec})**	**50 nJ/bit**
Transmit Amplifier ($€_{amp}$)	**100 pJ/bit/m^2**

Table(3.1) (Heinzelman, 2000)

By considering the first order model to compute the transmission and receiving power, if A ***k***-bit message will be routed a distance ***d*** using the first radio model, the radio expends:

$$E_{Tx}(k,d) = E_{Tx\text{-}elec}(k) + E_{Tx\text{-}amp}(k,d) \qquad 3.7.(a)$$

Where

$E_{Tx\text{-}elec}$: is the transmitter electronic dissipated energy and it is equal to 50 nJ/bit.

$E_{Tx\text{-}amp}$: is the transmit amplifier dissipated energy and it is equal to 100 pJ/bit/m^2.

k: is the message size measured by bit.

d: is the distance measured by meter between s_i node and t_i node.

Then,

$$E_{Tx}(k,d) = Eelec * k + €_{amp} * k * d^2 \qquad 3.7.(b)$$

And to receive this message, the radio expends:

$$E_{Rx}(k) = E_{Rx\text{-}elec}(k) \qquad 3.8.(a)$$

Where

$\boldsymbol{E_{Rx\text{-}elec}}$**:** is the Receiver Electronics dissipated energy and it is equal to 50 nJ/bit.

$\boldsymbol{k}$: is the message size measured by bit.

Then

$$\boldsymbol{E_{Rx}(k) = E_{elec} * k} \qquad 3.8.(b)$$

For these parameter values, receiving a message is not a low cost operation; the previous work represent a new power management technique by dividing the power at node level to be tow ratio, one for data originated from the node (α), the other is for relays from other sensors (β), (Reema Hosny, 2009), in our work we conserve this technique and we use the realistic power consumption equations to compute the transmission and receiving power.

We consider the message size k = 2000 bit, and an initial sensor power ie = (0.5 j), We make the assumption that the radio channel is symmetric such that the energy required to transmit a message from node A to node B is the same as the energy required to transmit a message from node B to node A, (Hienzleman, 2000).

To compute the transmission power at each node located in the route path Fig (3.4), where the distance between the nodes is d, a single k-bit message from a node A located a distance (r.n) from B, where n =1, because the power transmitting computation is performed for each tow consecutive nodes in the route path that is found by shortest path algorithm, we repeat the operation along the shortest path to compute power transmission consumptions using equation 3.9.(b)

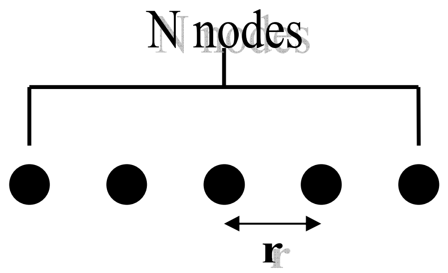


Fig 3.4: simple linear network

$E_{Tx}(k,d=n*r) = E_{elec} * k + €_{amp} * k * (nr)^2$ 3.9.(a)

Where n=1

$E_{Tx}(k,d=n*r) = E_{elec} * k + €_{amp} * k * (d)^2$ 3.9.(b)

Where

$E_{Tx\text{-}elec}$: is the transmitter electronic dissipated energy and it is equal to 50 nJ/bit.

$E_{Tx\text{-}amp}$: is the transmit amplifier dissipated energy and it is equal to 100 pJ/bit/m^2.

k: is the message size measured by bit.

d: is the distance measured by meter between s_i node and t_i node.

The next two figures explains the steps and procedures that our model that based on Hienzleman equations follows in ERPMT_CH and ERPMT_OH:

Heuristic 1 ERMPT_CH

Assumption: Divide the current energy of each sensor into c_{e1} and c_{e2}:

$c_{e1} = i_e * \alpha$ and $c_{e2} = i_e - c_{e1}$

where

i_e : is the total energy.

α : is the ratio of power dedicated to the data originated from the node itself.

For each routing request r_i = (s_i , t_i) two steps are done:

Step 1: [Initialize]

(a) assign weight of every edge (u, v):

$$W(u,v) = E_{Tx}(k,d) = E_{elec} * k + €_{amp} * k * d^2$$

Where

K: is the message size.

d: is the distance between s_i and t_i.

E_{elec}: is the transmitter electronic dissipated energy and it is equal to 50 nJ/bit.

$€_{amp}$: : is the transmit amplifier dissipated energy and it is equal to 100 pJ/bit/m^2

(b) Eliminate from ***G*** every edge (u, v) for which:

$c_{e1}(u) < E_{Tx}(k,d)$ if $u = s_i$

$c_{e2}(u) < E_{Tx}(k,d)$ & $c_{e2}(u) < E_{Rx}(k)$ if $u \neq s_i$ & $u \neq t_i$

$c_{e2}(u) < E_{Rx}(k)$ if $u = t_i$

ɔ 2: [Shortest Path]

find ***P,*** where ***P*** is the shortest source-to-destination path in the modified Graph ***G′*** based on Dijikstra.

Step 3: [Wrap Up]

If no path is found in Step 2, the route is not possible. Use ***P*** for route if its length is less than σ.

Fig 3. 5: ERPMT_CH Heuristics.

Heuristic 2 ERPMT_OH

Assumption: Divide the current energy of each sensor into c_{e1} and c_{e2} :

$c_{e1} = i_e * \alpha$ and $c_{e2} = i_e - c_{e1}$

where

i_e : is the total energy.

α : is the ratio of power dedicated to the data originated from the node itself.

For each routing request $r_i = (s_i, t_i)$ two steps are done:

Step 1: [Compute G']

(a) assign weight of every edge (u, v):

$$W(u,v) = E_{Tx}(k,d) = E_{elec} * k + €_{amp} * k * d^2$$

Where

K: is the message size.

d: is the distance between s_i and t_i.

E_{elec}: is the transmitter electronic dissipated energy and it is equal to 50 nJ/bit.

$€_{amp}$: : is the transmit amplifier dissipated energy and it is equal to 100 pJ/bit/m^2

(b) Find P_i where P_i is the shortest s_i to t_i path in G', based ob dijikstra.

If there is no such P_i, the route request fails, then stop.

(c) Compute the minimum residual energy minRE for sensors other than t_i on P_i as :

$$minRE = min\{r(u) \mid in\ P\}$$

$$r_e(u) = \begin{cases} c_{e1}(u) - E_{Tx}(k,d) & \text{if } u = s_i \\ c_{e2}(u) - (E_{Tx}(k,d) + E_{Rx}(k)) & \text{if } u \neq s_i \ \&\ u \neq t_i \\ c_{e2}(u) - E_{Rx}(k) & \text{if } u = t_i \end{cases}$$

(d) Let $G''=(V,E')$:

$$\text{where } E' = \begin{cases} E-(u,v) \ \ if \ \ c_{e1}(u) - E_{Tx}(k,d) < minRE & \text{if } u = s_i \\ E-(u,v) \ \ if \ \ c_{e2}(u) - (E_{Tx}(k,d) + E_{Rx}(k)) < minRE & \text{if } u \neq s_i \ \&\ u \neq t_i \\ E-(u,v) \ \ if \ \ c_{e2}(u) - E_{Rx}(k) < minRE & \text{if } u = t_i \end{cases}$$

Step 2: [Find route path]

(a) Find Pi'' be a shortest from s_i to t_i path in G''.

Figure 3.6: ERPMT_OH Heuristic

4. Experiments and Results

The realistic power consumption model based on Heinzelman equations was implemented in Matlab, the Operating System was Windows XP SP3 installed on a PC with 2.0 GHz processor and 1.24 GB of RAM. The OML (Online Maximum Lifetime) , the CMAX (Capacity Maximization), ERPMT_C, and ERPMT_O were implemented using the new realistic power consumption model, the result was new heuristics, CMAX_H, OML_H, ERPMT_CH, and ERPMT_OH, the new heuristics were implemented in Uniform and Poisson distributions for both 1D and 3D dimensions. In each of 10 networks 20 sensors were randomly populated. The energy required by a single-hop transmission between two sensors was assumed to be ($E_{elec}*k$ + $€amp*k*d^2$) where E_{elec} is the power consumes by the radio (50 nJ/bit) to run the transmitter or receiver circuitry, k is the message size was set to be (2000 bit). $€_{amp}$ is the energy consumes by the transmit amplifier. Finally, d is the distance between tow nodes have a connection between them, every node has initial power (0.5 J), (Heinzelman, 2000). But in ERPMT_C and ERPMT_O, the power at each sensor has been divided into two ratios of the total node energy; the first is for the data sent by the sensor itself (α), the other is for data relays from other sensors (β). These two ratios were divided in two ways; the first by dedicating less power than or equal to β for α, the second is done by assigning higher power than β for α. Table(4.1) summarizes the initial conditions of the simulations.

Table (4.1) Initial **conditions**

Initial Conditions	
Network size	20 sensor
Message size	2000 *bits*
Initial energy for each sensor	0.5 *J*
Energy consumes by the radio to run transmitter/receiver circuitry	50 *nJ/bit*
Energy consumes by the transmit amplifier	100 $pJ/bit/m^2$

The simulation results show the effect of applying different power division's ratios for α. And β, also the results show the effects of applying the realistic power consumption model in different distribution types on the network lifetime.

The main objective for this thesis is to test the effect of applying our new realistic power consumption model to the existing energy aware routing heuristics for extending lifetime, such as OML which obtain the best lifetime in the literature and the CMAX which achieves less life time when compared to OML, so on, OML_H which achieve best lifetime when compared to CMAX_H, also ERPMT_CH and ERPMT_OH, where ERPMT_CH achieves less life time when compared to ERPMT_OH.

4.1. Dedicating power less than or equal to β for α

Here α was 50%, 40%, 30%, 20%, and 10% of total node energy.

4.1.1. Average lifetime using Uniform distribution for α ≤ β

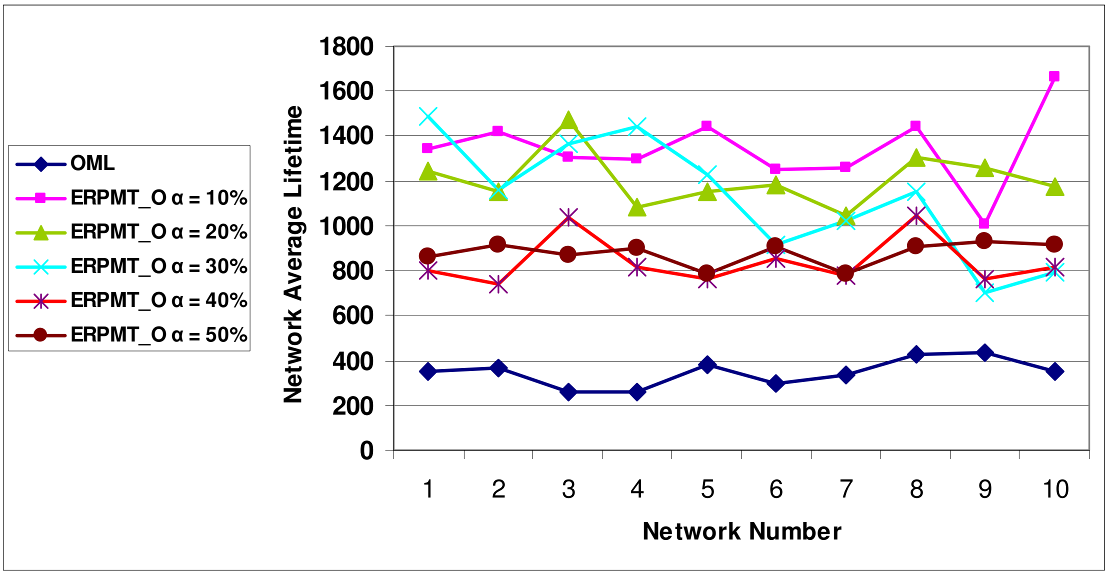


Figure 4.1: Average lifetime routing for OML_H and ERPMT_OH (α≤ β) using Uniform Distribution

Fig.4.1 shows average lifetime for OML_H and ERPMT_OH, 10 networks were implemented with 20 sensors in each network, the average lifetime for α = 10%, 20%, 30%, 40%, 50% is 1342, 1206, 1127, 841, 879, respectively. It is clear from the graph that for the case of α=10% has the highest average lifetime were achieved by ERPMT_OH which is completely differs in the previous work result where the case α=10% had the lowest average lifetime and when α=50% the best lifetime was achieved in previous work, in our work for α= 40% the lowest average lifetime was achieved. Generally, ERPMT_OH achieves best life time than OML_H when (α≤ β) using Uniform Distribution, which is agreed with previous work.

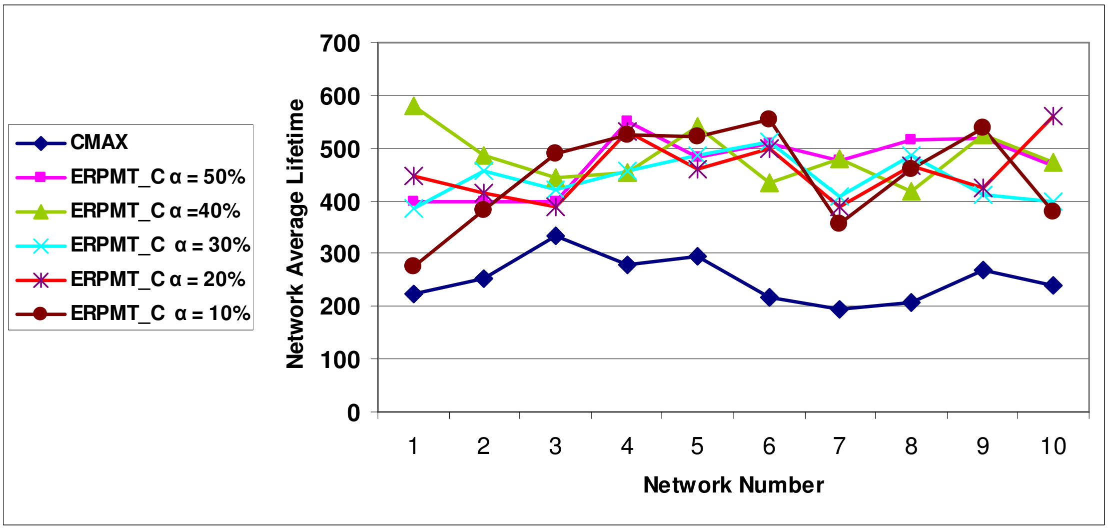


Figure 4.2: Average lifetime routing for CMAX_H and ERPMT_C_H (α≤ β) using Uniform Distribution

Fig 4.2 shows that for α = 10%, 20%, 30%, 40%, 50% the average lifetime is 449, 458, 443, 484, and 471, respectively. ERPMT_CH achieves the highest average lifetime when α = 40% and lowest average life time achieved by ERPMT_CH when α= 30%.which differs with the previous work, where the highest average lifetime achieved when α=50%, and the lowest life time achieved when α= 10%.

Fig 4.2 also shows that the ERPMT_CH still has the best life time than CMAX_H, which is agreed with previous work.

Table 4.2 and Table 4.3 shows the percentage difference in life time between OML_H and ERPMT_OH, CMAX_H and ERPMT_CH, respectively, in different cases of α where α≤ β and the distribution is Uniform, we used equation 4.1 to compute the percentage difference, if the result is negative that mean there is reduction in lifetime. Else, it is an improvement in network lifetime.

$$\textbf{\% Difference} = \frac{(\textbf{Avg.ERPMT_OHAvg.OML_H})}{(\textbf{Avg.ERPMT_OH})} \times \textbf{100\%} \qquad 4.1$$

Table 4.2: Percentage difference between OML_H and different cases of ERPMT_OH (α ≤ β) using Uniform Distribution.

Technique used	OML_H	ERPMT_OH				
		α=50%	**A**=40%	**A**=30%	**α**=20%	**α**=10%
Avg. Lifetime	346.17	878.66	840.58	1126.92	1205.56	1342
Percentage Diff.		+60.60%	+58.82%	+69.28%	+71.29%	+74.20%

Table 4.3: Percentage difference between CMAX_H and different cases of ERPMT_CH (α ≤ β) using Uniform Distribution

Technique used	CMAX_H	ERPMT_CH				
		α=50%	**α**=40%	**A**=30%	**α**=20%	**α**=10%
Avg. Lifetime	251.41	471.27	483.65	442.54	458.08	448.68
Percentage Diff.		+46.64%	+48.02	+43.19	+45.12	+43.97

Generally, using consumption model based on Heinzelman equations and realistic variables shows that applying ERPMT power management technique to the OML and CMAX where (α ≤ β) in Uniform Distribution gained higher average life time than CMAX and OML without using the ERPMT technique, which is agreed with the previous work.

4.1.2. Average lifetime using Poisson distribution for α ≤ β

In our work, we implement OML_H and ERPMT_OH in Poisson distribution for the same case when α ≤ β, this changing in distribution gives a lower lifetime when it is compared to Uniform distribution for the same case when α ≤ β.

Figure 4.3 shows that in case of using Poisson distribution in implementing OML_H and ERPMT_OH the average lifetime for α = 10%, 20%, 30%, 40%, 50% is 911, 895,

890, 832, 889, respectively. ERPMT_OH achieves the highest average lifetime when α = 10% and lowest average lifetime when α = 40%, in the previous work ERPMT_O achieved highest average lifetime when α = 50 and lowest average lifetime when α = 10%.

Generally, ERPMT_OH achieves best life time than OML_H when (α≤ β) using Poisson distribution, which is agreed with previous work.

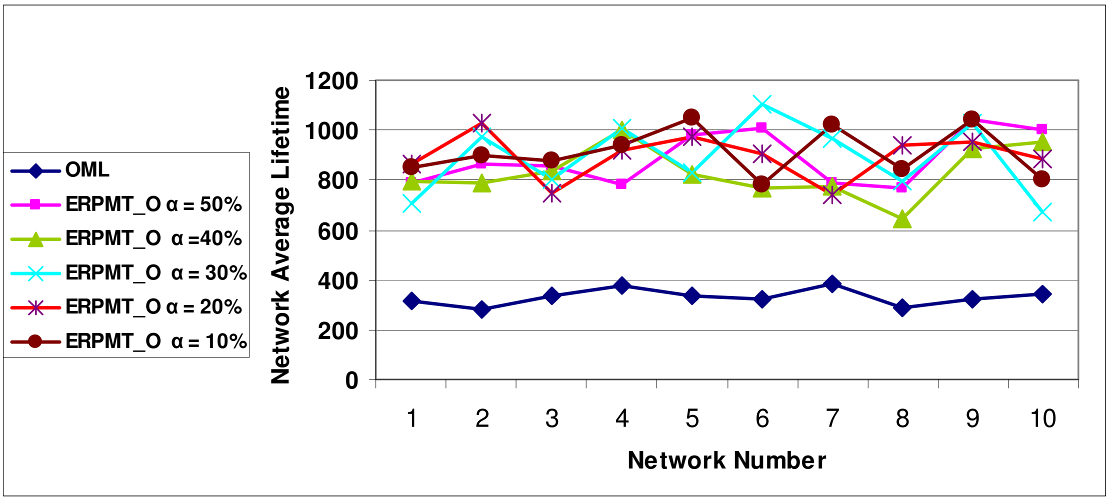


Figure 4.3: Average lifetime routing for OML_H and ERPMT_OH (α≤ β) using Poisson distribution

Fig.4.4 shows different results of implementing CMAX_H and ERPMT_CH in Poisson distribution, the average lifetime for α = 10%, 20%, 30%, 40%, 50% is 880, 834, 857, 847, and 858, respectively. ERPMT_CH achieves highest average lifetime when α = 10% and lowest average lifetime when α = 20%. In previous work, the ERPMT_C achieves highest average lifetime when α = 50% and lowest average lifetime when α = 10%.

Generally, ERPMT_CH achieves best life time than CMAX_H when (α≤ β) using Poisson distribution, which is agreed with previous work

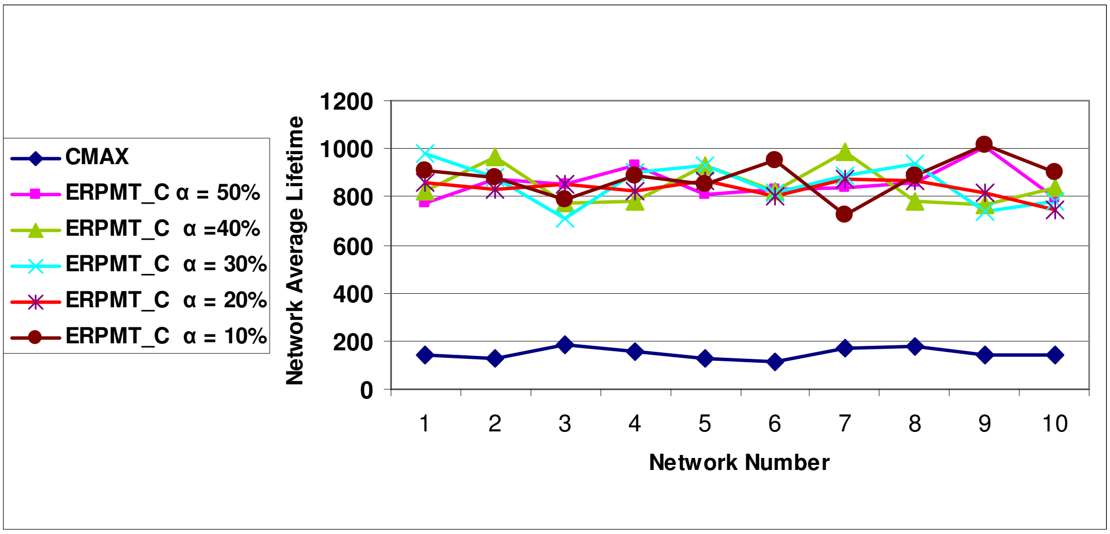


Figure 4.4: Average lifetime routing for CMAX_H and ERPMT_CH (α≤ β) using Poisson distribution.

Table 4.4 and Table 4.5 shows the percentage difference in life time between OML_H and ERPMT_OH, CMAX_H and ERPMT_CH, respectively, in different cases of α where α≤ β where the distribution is Poisson.

Table 4.4: Percentage difference between OML_H and different cases of ERPMT_OH (α ≤ β) using Poisson distribution.

Technique used	OML_H	ERPMT_OH				
		α=50%	**α=40%**	**A=30%**	**α=20%**	**α=10%**
Avg. Lifetime	331.29	888.7	831.93	889.57	895.4	911.02
Percentage Diff.		62.72%	60.18%	62.76%	63%	63.64%

Table 4.5: Percentage difference between CMAX_H and different cases of ERPMT_CH (α ≤ β) using Poisson distribution.

Technique used	CMAX_H	ERPMT_CH				
		α=50%	**α=40%**	**α=30%**	**α=20%**	**α=10%**
Avg. Lifetime	147.97	857.55	847.36	856.8	834.11	879.96
Percentage Diff.		+82.75	+82.54	+82.73	+82.26	+83.18

Generally, in our work using consumption model based on Heinzelman equations and realistic variables shows that applying ERPMT power management technique to the OML and CMAX where (α ≤ β) in Poisson Distribution gained higher average life time than CMAX and OML without using the ERPMT technique, which is agreed with the previous work.

In previous work, ERPMT_C and ERPMT_O for the case where (α ≤ β) for the two distributions (Uniform and Poisson) they noticed that the network lifetime increased by increasing the energy ratio dedicated for the sensor own data .In our work and in the two heuristics ERPMT_CH and ERPMT_OH there isn't a static rule such that the increasing of the energy ratio dedicated for the sensor own data causes increasing in the average lifetime of the network.

4.2. Dedicating more power for α than β

Here α was set to 60%, 70%, 80%, 90%, 100%.

4.2.1. Average lifetime using Uniform distribution for α > β

Fig.4.5 shows the average lifetime for α = 60%, 70%, 80%, 90%, 100% is 900, 891, 852, 880, 898, respectively. ERPMT_OH achieves the highest average lifetime when α = 60% and lowest average lifetime when α = 80% whish differs with the previous work where ERPMT_O achieves highest average lifetime when α = 60% and lowest average lifetime when α = 100%. ERPMT_OH achieves best life time than OML_H when (α > β) using Uniform Distribution, in the previous work when (α > β) and the distribution was Uniform the OML achieves best average lifetime more than ERPMT_O (except the case where α = 60%).

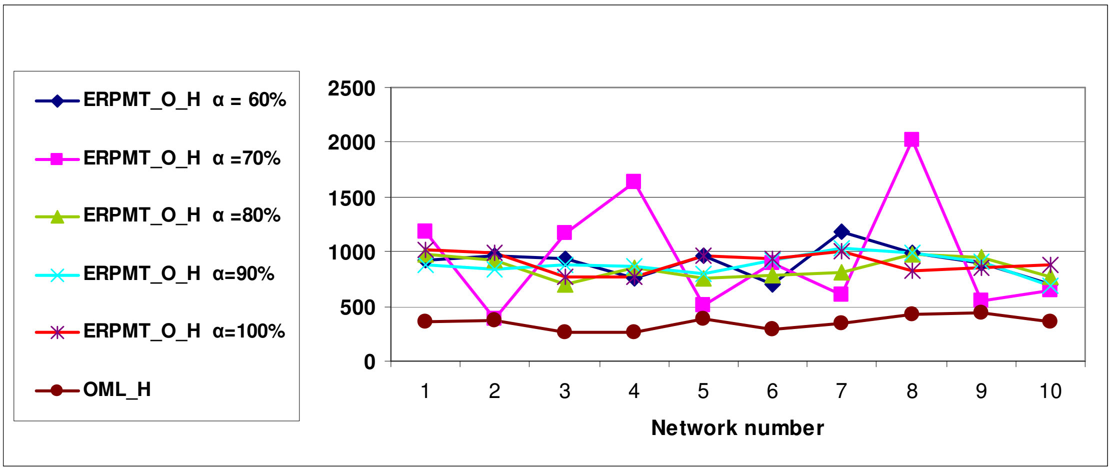


Fig 4.5: Average lifetime routing for OML_H and ERPMT_OH (α > β) using Uniform distribution.

Fig 4.6 shows the average lifetime for α = 60%, 70%, 80%, 90%, 100% is 456, 475, 453, 478, 458, respectively. The ERPMT_CH achieves highest average lifetime when α = 90% and lowest average lifetime when α = 80%, in previous work ERPMT_C achieves highest average lifetime when α = 60% and lowest average lifetime when α = 100%.

ERPMT_CH achieves best life time than OML_H when (α > β) using Uniform Distribution, in the previous work when (α > β) and the distribution was Uniform the CMAX achieves best average lifetime more than ERPMT_C for all cases of α. So, The ERPMT_CH still has the superiority over CMAX_H which differs with the previous work.

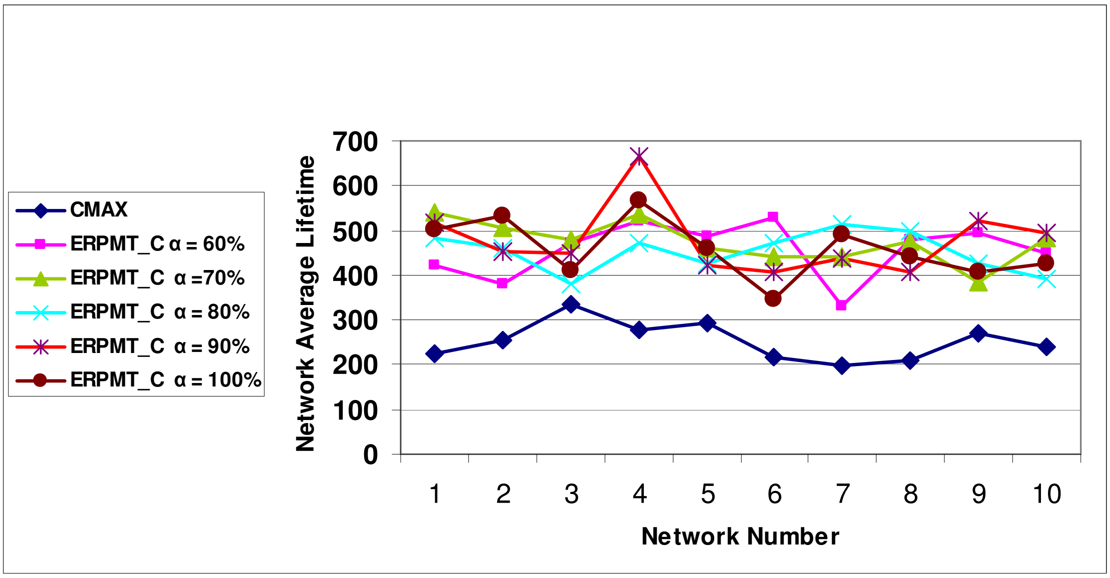


Fig 4.6 Average lifetime routing for CMAX_H and CMAX_OH (α > β) using Uniform distribution.

Table 4.6 and Table 4.7 shows the percentage difference in life time between OML_H and ERPMT_OH, CMAX_H and ERPMT_CH, respectively, in different cases of α where α> β where the distribution is Uniform.

Table 4.6: Percentage difference between OML_H and different cases of ERPMT_OH (α > β) using Uniform distribution

Technique used	OML_H	ERPMT_OH				
		α=60%	**α=70%**	**A=80%**	**α=90%**	**α=100%**
Avg. Lifetime	346.17	900.02	891.32	851.95	879.95	898.01
Percentage Diff.		+61.54%	+61.16%	+59.37%	+60.66%	+61.45%

Table 4.7: Percentage difference between CMAX_H and different cases of ERPMT_CH (α > β) using Uniform distribution

Technique used	CMAX_H	ERPMT_CH				
		α=60%	**α=70%**	**α=80%**	**α=90%**	**α=100%**
Avg. Lifetime	251.41	456.31	474.77	452.74	477.6	458.3
Percentage Diff.		+44.90	+47.05	+44.47	+47.36	+45.14

Generally, in our work using consumption model based on Heinzelman equations and realistic variables shows that applying ERPMT power management technique to the OML and CMAX where (α > β) in Uniform Distribution gained higher average lifetime than CMAX and OML without using the ERPMT technique, which is differs with the previous work for the same case where (α > β) in the Uniform distribution.

The two heuristics ERPMT_CH and ERPMT_OH there is not a static rule such that the increasing of the energy ratio dedicated for the sensor own data causes increasing in the average lifetime of the network

4.2.2. Average lifetime using Poisson distribution for α > β

Fig 4.7 shows the average lifetime for α = 60%, 70%, 80%, 90%, 100% is 891,891, 854, 880, 840, the ERPMT_OH achieves the highest average lifetime when α = 60% and lowest average lifetime when α = 100%.

In our work, ERPMT_OH still has the superiority over OML_H, in the previous work for all cases (α > β) and in Poisson distribution OML achieves the best lifetime average over ERPMT_O.

Fig 4.8 shows the average lifetime for α = 60%, 70%, 80%, 90%, 100% is 862, 848, 818, 828, 891, ERPMT_CH has the superiority over the CAMX_H, which differs with the previous work where CMAX achieves the best average lifetime over ERPMT_C for all cases where (α > β) except the case where α = 60%.

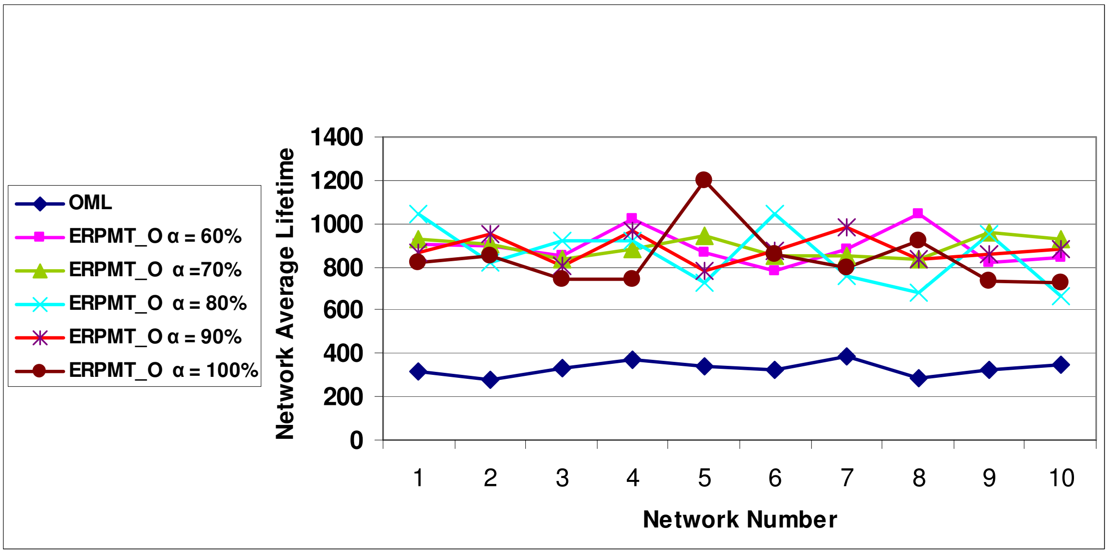


Figure 4.7: Average lifetime routing for OML_H and ERPMT_OH (α > β) using Poisson distribution.

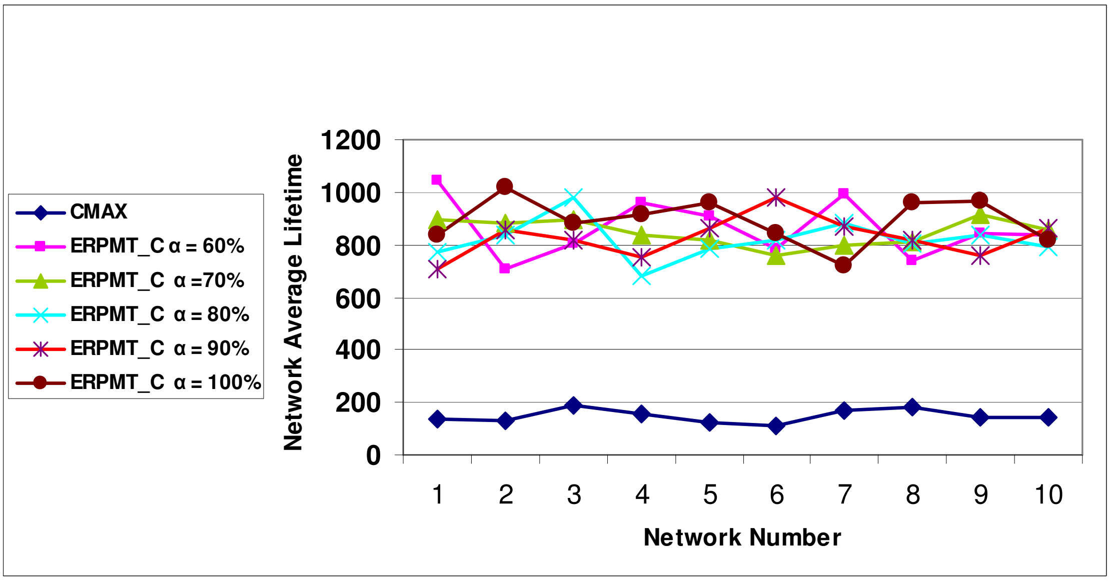


Figure 4.8: Average lifetime routing for CMAX_H and ERPMT_CH (α > β) using Poisson distribution.

Table 4.8 shows the best life time was gained by ERPMT_OH where α = 60%, but we didn't observe a clear decreasing or increasing as α increasing, ERPMT_OH still has the better life time than OML_H.

Table 4.8: Percentage difference between OML_H and different cases of ERPMT_OH (α > β) using Poisson distribution.

Technique used	OML_H	ERPMT_OH				
		α=60%	α=70%	α=80%	α=90%	α=100%
Avg. Lifetime	331.29	890.84	890.64	853.83	880.19	840.4
Percentage Diff.		+62.81%	+62.79%	+61.20%	+62.36%	+60.58%

Table 4.9 shows the best life time was gained by ERPMT_CH where α = 100%, but we didn't observe a clear decreasing or increasing as α increasing, ERPMT_CH still has the better life time than CMAX_H.

Table 4.9: Percentage difference between CMAX_H and different cases of ERPMT_CH (α > β) using Poisson distribution.

Technique used	CMAX_H	ERPMT_CH				
		α=60%	α=70%	α=80%	α=90%	α=100%
Avg. Lifetime	147.97	861.76	847.93	817.83	828.14	890.92
Percentage Diff.		+82.83	+82.55	+81.91	+82.13	+83.39

4.3. Effect of network size on network lifetime

We conclude from our experiment that as the number of sensors increases the average lifetime of the network decreases. Our interpretation to our result that by increasing the number of sensors in the network, the number of links between sensors increase also, which mean the number of nodes that are going to play the intermediate nodes in each route will increase also, these nodes are the biggest loser in each route in energy wise, it will dissipate transmission and receiving energy, which causes their early energy depletion.

As the network has more sensors this increases the opportunity to make more connections between nodes which leads to more communications that dissipate more energy in transmissions.

Fig 4.9 shows the average lifetime for ERPMT_OH with different number of sensor nodes using Poisson distribution where (α = 10% of the total energy).

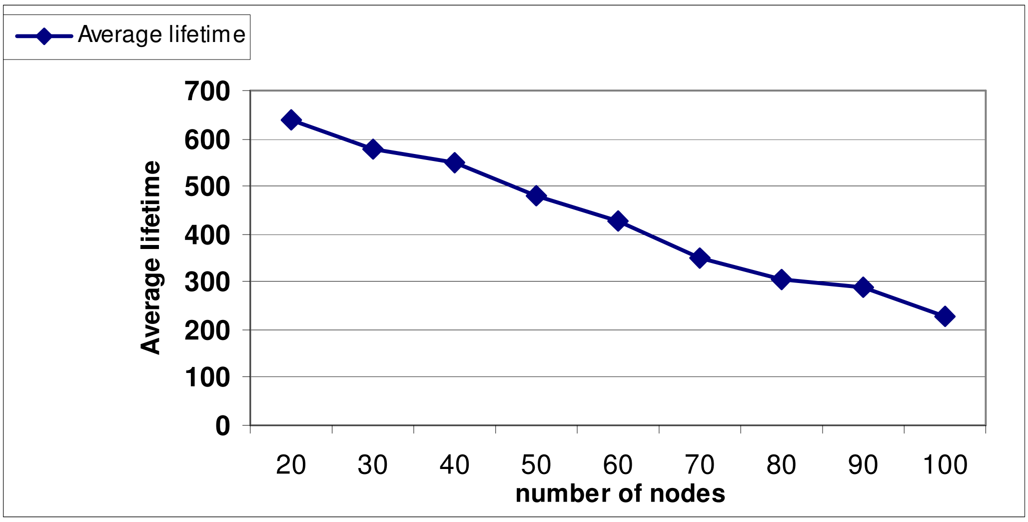


Fig 4.9: Average lifetime for ERPMT_OH with different number of sensor nodes using Poisson distribution where (α = 10% of the total energy).

4.4 Effect of changing the representation from 1D to 3D

Fig 4.10 shows a comparison between 3D ERPMT_OH in Poisson and Uniform distributions where α = 10%, in case of Uniform distribution the life time average is 794, and for the Poisson distribution the average lifetime is 762.

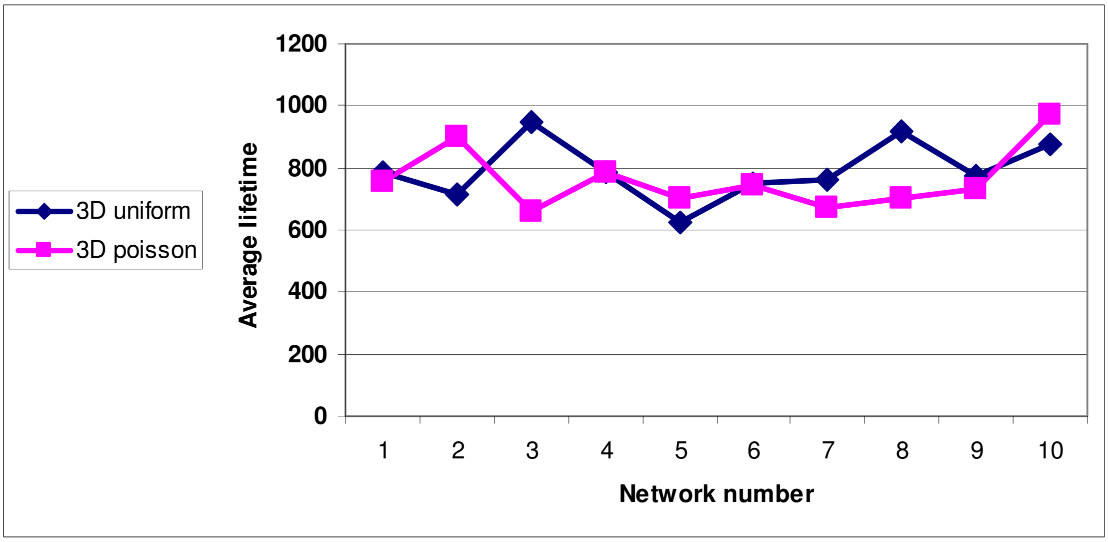


Fig 4.10: Comparison between Average lifetime for 3D ERPMT_OH in Poisson and Uniform distributions where α = 10%.

This result is Consistent with the fact about Poisson distribution, in Poisson distribution the number of links between nodes more than in Uniform distribution which causes more depletion in nodes energy, and effects directly by decreasing average lifetime of the network.

4.5 Implementing MICAz with the power consumption model based on Heinzelman equations

The MICAz is a 2.4 GHz Mote module used for enabling low-power, wireless sensor networks, Designed Specifically for Deeply Embedded Sensor Networks. In MICAz the energy cost to transmit each bit is (0.60 μJ) and (0.67 μJ), (Meulenaer, et al., 2008).

we implemented the MICAz using ERPMT_OH in Poisson and Uniform distribution where α = 10%, Fig 4.11 shows a comparison between MICAz implemented using ERPMT_OH in Uniform and Poisson distributions, the Average lifetime when the distribution was Uniform is 214, in Poisson distribution the average lifetime is 196.

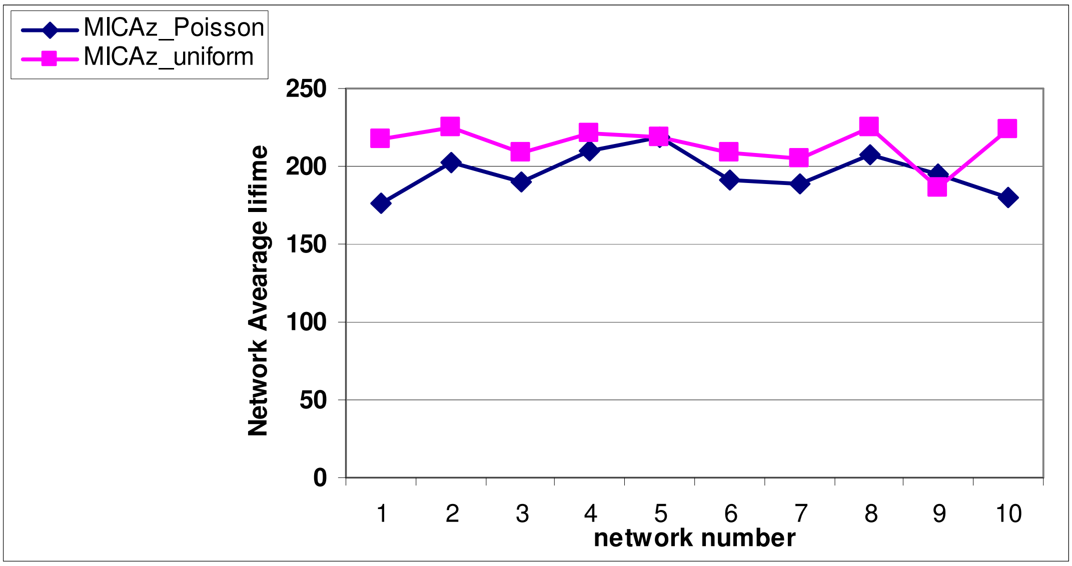


Fig 4.11: Comparison between MICAz implemented using ERPMT_OH in Uniform and Poisson distribution

As we discussed previously, in Poisson distribution the number of links between nodes is more than in Uniform distribution which causes more depletion in nodes energy, and effects directly by decreasing average lifetime of the network.

4.6 Energy depletion throughout simulation period

Fig 4.12 shows energy depletion throughout simulation period, in order to show how the energy gets depleted over time, until the network is unable to transmit any messages due to insufficient remaining energy. For that, we consider a hypothetical initial energy of sensors that is 20000 μJ rather than the 0.5 μJ and a message size of 2000 bits. Fig 4.12 depicts the total network energy over the simulation period time.

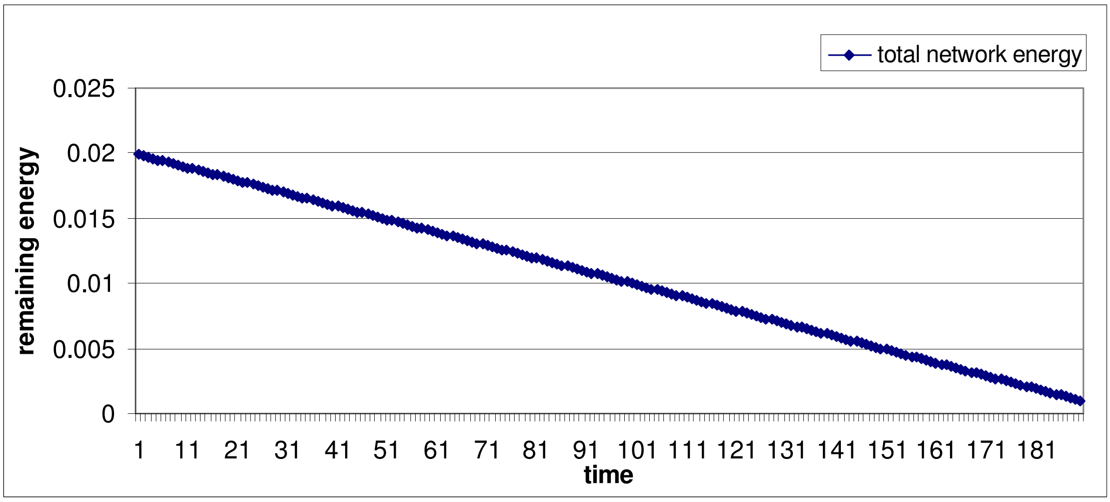


Fig 4.12: Energy depletion throughout simulation period.

5. Conclusion and Future Work

5.1. Conclusion

We introduced a realistic power consumption model based on Heinzelman equations, our model uses a realistic variables such as, the message size, the initial power for each node and the distances between nodes, our model was applied to four heuristics, the first two are OML and CMAX, the last two heuristics are enhancements over OML and CMAX it called ERPMT_C and ERPMT_O, where a power management technique was applied such that, the power at node level is divided into two ratio: α is for the data sent by the sensor itself and β is for data sent by other nodes.

The result of applied model on the last four heuristics introduced OML_H, CMAX_H, ERPMT_OH and ERPMT_CH, generally in our work OML_H achieve always higher network lifetime than CMAX_H. So on, ERPMT_OH achieves best network life time than ERPMT_CH, which is not the same with the previous work where CMAX and OML have better average lifetime than ERPMT_C and ERPMT_H for $\alpha > \beta$ in Uniform and Poisson distribution.

After execution an extensive runs shows that applying our realistic model, the best average lifetime was 74.20% when $\alpha = 10\%$ in ERPMT_OH, in Uniform distribution.

In our work, for all distributions and cases of α there isn't specific rule for decreasing or increasing for all other cases of α. Our realistic power consumption model proved the superiority of applying ERPMT (Efficient power management technique) over CMAX and OML for all cases of α which is proved in the previous work just where $\alpha \leq \beta$.

We studied the effect of increase the network size on average lifetime, we found the increasing in number of nodes cause more depletion in nodes power specially in intermediate nodes, cause the opportunity for more path could be found, those nodes consumes transmission and receiving power in the same time, deplete nodes power decrease the average lifetime of the network.

In ERPMT_H changing the representation of the network sensors into 3D results in decreased the lifetime, also, when we change the distribution from Uniform to Poisson decreases the lifetime in case of 3D and 1D, this is because the most of the nodes are closed to each other, which increase the number of links between nodes this can increase the transmission and receiving power specially in intermediate nodes in each route.

Implementing case study like MICAz using ERPMT_OH in Uniform distribution achieves higher average lifetime than when it is implemented in Poisson distribution.

5.2. Future Work

In our future work, we will study the effects of categorizing sensors according to their importance in the network, if the sensor has a high priority then $\alpha >> \beta$, if the sensor has low priority then $\alpha << \beta$, and so on.

The next study will be in prioritizing the sensors according to the importance in the network.

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تأثير نماذج استهلاك الطاقة في تقنيات التوجيه في شبكات الاستشعار اللاسلكية

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الملخص

تتكون شبكات الاستشعار اللاسلكية من عدد كبير من عقد الاستشعار، تتضمن العقدة معالج و وجهاز راديوي وأجهزة استشعار أخرى، تتعاون العقد فيما بينها لإنجاز مهمة مشتركة.

يتم تزويد عقد الاستشعار بالطاقة من خلال بطاريات محدودة القدرة،ولما كانت بث البيانات عن طريق الموجات الراديوية السبب الرئيسي في استهلاك الطاقة فإنه يجب الاقتصاد في عملية إرسال واستقبال البيانات قدر المستطاع. من الضروري استخدام تقنيات تجد مسارات تستهلك الطاقة الأقل حيث ان استهلاك طاقة عقد الاستشعار يسبب المناطق العمياء في الشبكة.

أحدث الأبحاث التي أجريت في مجال إطالة عمر الشبكة تمت من خلال التقنيتين OML و CMAX، كلا التقنيتين تمت دراستهما وتحليلهما إحصائيا وبناء على متغيرات عشوائية.

في دراسات سابقة تم تقديم تقنية جديدة للحصول على عمر و تغطية أعلى للشبكة عن طريق إدارة الطاقة على مستوى العقدة عن طريق تقسيم طاقة العقدة إلى قسمين : الأول لنقل للبيانات التي تنشأ من العقدة نفسها(α), والآخر لتوصيل البيانات من العقد الأخرى(β). هذه التقنية, و التي تدعى (تقنية فعالة للتوجيه و إدارة الطاقة), قد طبقت على OML و CMAX للحصول على النسخ المعدلة منها و التي هي ERPMT_O و ERPMT_C على الترتيب بهدف دراسة اثر ذلك على عمر الشبكة, الطاقة المستهلكة, و التغطية.

في هذه الرسالة قمنا بتقديم نموذج حقيقي لاحتساب استهلاك الطاقة يستند الى معادلات Hienzleman باستخدام متغيرات حقيقة، مثل حجم الرسالة،المسافة بين العقد و الطاقة الأولية لكل عقدة استشعار، كل هذه المتغيرات الحقيقة تم استخدامها في احتساب الطاقة المستهلكة لإرسال واستقبال البيانات في كل عقدة واقعة على أقصر مسار تم إيجاده بتقنية CMAX و OML و ERPMT_C و ERPMT_O .
بعد تطبيق النموذج الحقيقي على التقنيات الأربعة السابقة ظهرت أربعة تقنيات جديدة هي: CMAX_H و OML_H و ERPMT_CH و ERPMT_OH.

في هذه الرسالة وبغية إجراء دراسة واقعية في استهلاك الطاقة في أجهزة الاستشعار اللاسلكية تمت دراسة تأثير اختلاف التضاريس الأرضية من خلال تنفيذ التقنيات الأربعة على أساس التوزيعات المختلفة والتي تمثل حالات مختلفة من نشر أجهزة الاستشعار اللاسلكية.

كشفت نتائج دراستنا عن تفوق التقنيتين ERPMT_CH و ERPMT_OH على التقنيتين CMAX_H و OML_H على الترتيب، ولكن بقيت التقنية OML تحقق تفوقا على التقنية CMAX وهذا يتفق مع الدراسة السابقة.

في دراستنا حققت التقنية ERPMT_OH أفضل متوسط عمر للشبكة مقارنة بمتوسط العمر الذي حققته OML_H اذ بلغت نسبة التحسن 74.20% عندما كانت α =10%، عندما تم تنفيذه بناء على التوزيع الموحد، أما بخصوص التقنيات الثلاثة الأخرى فعندما تم تنفيذها باستخدام التوزيعات المختلفة وبتقسيم طاقة العقدة الى نسب مختلفة فلم يكن هناك استراتيجية واضحة في زيادة أو انخفاض معدل عمر الشبكة مع اختلاف تقسيم طاقة العقدة.

وعند دراستنا لنظام شبكات استشعار لاسلكية يدعى (MICAz) كحالة للدراسة توافقت نتائج تنفيذ النظام في التوزيعين (الموحد وباوسون) مع نتائج ال ERPMT_H.